APPENDIX B. LIST OF SYMBOLS

	Α Δ Φ Θ Ρ Ω	*A B C D E F G H I J K L M N O P Q R S T U V W X Y Z*			
Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	Greek				
Α α					
	$\alpha(\lambda), \alpha(z,\lambda)$	Atmospheric attenuation coefficient	m^{-1}	(3.1.1)	**3.1.1**
	$\alpha\left(z_{sf}(\mathbf{r}), \mathbf{r}\right)$	Angle between the local normal to the surface at a boundary and the lidar beam axis, Oz		(4.3.29)	**4.3.2.4**
Β β					
	$\beta, \beta(\theta), \beta(\boldsymbol{r},\theta), \beta(\boldsymbol{n})$	Volume scattering function (VSF) – may depend on coordinate **r** or directional vector **n**	$m^{-1}sr^{-1}$	(3.3.5)	**3.3.2.2**
	$\beta(z,\boldsymbol{r},\boldsymbol{n}_1\wedge\boldsymbol{n}_2)$	The volume scattering function for the angle $\boldsymbol{n_1}\wedge\boldsymbol{n_2}$, where $\boldsymbol{n_1}$ is the direction of beam propagation and $\boldsymbol{n_2}$ is the direction of the scattered light; the function is taken to be zero if the point $\{z(t),\mathbf{r}\}$ is not within the water body. When the water is vertically and horizontally homogeneous, then $\beta(z,\boldsymbol{r},\boldsymbol{n}_1\wedge\boldsymbol{n}_2)\equiv\beta(\boldsymbol{n}_1\wedge\boldsymbol{n}_2)$	$\mathrm{m}^{-1}\mathrm{sr}^{-1}$	(4.3.16)	**4.3.2.2**
	β_π	Lidar backscattering coefficient	$m^{-1}sr^{-1}$	After (3.3.12)	**3.3.2.2**
	$\beta_{atm}(z,\lambda)$	Atmospheric backscattering coefficient	$m^{-1}sr^{-1}$	(3.1.5)	**3.1.2**
	$\beta_{lg}(\theta)$	Large particle volume scattering function	$m^{-1}sr^{-1}$	(5.2.10)	**5.2**
	β_{sg}	Average bending angle of the seagrass leaf orientation with respect to the zenith	deg	(3.4.6)	**3.4.3**
	$\beta_{sm}(\theta)$	Small particle volume scattering function	$m^{-1}sr^{-1}$	(5.2.10)	**5.2**
	$\beta_w(\theta)$	Volume scattering function for pure sea water	$m^{-1}sr^{-1}$	(5.2.10)	**5.2**

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	Α Δ Φ Θ Ρ Ω	*A B C D E F G H I J K L M N O P Q R S T U V W X Y Z*			
Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
Γ γ					
	$\gamma(z(t), \mathbf{r})$	Function characterizing the reflection/scattering behavior of irradiance on the leading-edge plane at boundary surfaces (air-water interface, bottom, solid body in the water).	---	(4.3.28)	**4.3.2.4**
Δ δ					
	δ	delta function	---	(3.3.16)	**4.3.2.2**
	δ_2	A 2D delta function	---	(4.3.62)	**4.3.2.7**
Η η					
	η	Total optical system loss factor	---	(3.1.5)	**3.1.2**
	η_R	Transmittance of the receiver optical system	---	after (4.4.1)	**4.4.1**
Θ θ					
	θ	Scattering angle	rad, deg	after (3.3.5)	**3.3.2.2**
		Scanning angle		(5.1.1)	**5.1.1**
	θ_1	Incidence angle	rad, deg	(3.2.1)	**3.2.1**
	θ_2	Transmission angle (angle of refraction)	rad, deg	(3.2.1)	**3.2.1**
	θ_a	The angle between the emitted lidar beam axis and the local perpendicular to the water surface	rad, deg	(3.2.2); Figure 3.2.1	**3.2.1**
	θ_c	Zenith angle of a collimated beam incident to the seagrass bed plane	rad, deg	(3.4.6)	**3.4.3**
	θ_{max}	Maximum scan angle	rad, deg	(4.1.2)	**4.1.2**
	θ_{sun}	Solar zenith angle in air	rad, deg	(3.4.4)	**3.4.2**
	θ_a^{sun}			Table 5.1	**4.3**
	θ_{sg}	average bending angle of the seagrass leaf orientation with respect to the zenith	rad, deg	(3.4.6); Figure 3.4.3	**3.4.3**
	θ_w	Refraction angle in the water;	rad, deg	(3.2.2); Figure 3.2.1	**3.2.1**

	Α Δ Φ Θ Ρ Ω	*A B C D E F G H I J K L M N O P Q R S T U V W X Y Z*			
Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	θ_w^{sun}	Solar incidence angle in water	rad, deg	(5.3.1)	**5.3**
	Θ_E	The sounding pulse divergence - the full plane angle of conical distribution of emitted power at 1/e level	rad, deg	(4.1.1); Figure 4.2.1	**4.1.1**
	Θ_E'	The sounding pulse divergence (equivalent geometry)	rad, deg	Figure 4.2.4	**4.2.1**
	Θ_R	The angular width of lidar receiver sensitivity distribution (supposed conical) at 1/e level (FOV)	rad, deg	after (3.2.1)	**4.2.1**
	Θ_R'	The angular width of lidar receiver sensitivity distribution (equivalent geometry)	rad, deg	Figure 4.3.3	**4.3.2.2**
Κ κ					
	κ	yaw (boresight angle); The position vector in the IBF	rad, deg	(5.1.4)	**5.1.3**
Λ λ					
	λ	wavelength	nm	(3.3.1)	**3.3.1.2**
	λ	longitude	deg	(5.1.1)	**5.1.5**
Μ μ					
	μ	mean	–––	–––	**general**
Ρ ρ					
	ρ	reflectance coefficient	---	–––	**general**
	ρ	the target point	m	(6.3.1)	**6.3.2**
	ρ_{sf}	reflection coefficient of the water surface	---	after Figure 3.3.7	**4.2.2**
	ρ_w	(Effective) reflection coefficient of the water surface; not R_f or ρ_f		(3.4.1)	**3.4**
	ρ_{bot}	bottom reflectance	---	after (4.3.29)	**4.3.2**
	ρ_b	bottom reflectance	---	(3.4.1)	**3.4**
	ρ_{sb}	reflectance of a submerged, solid body	---	after (4.3.29)	**4.3.2**

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Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	ρ_{sg}	reflectance of sea grass	---	(3.4.6)	**3.4.3**
$\Sigma\ \sigma$					
	σ	Standard deviation	–––	–––	**general**
	σ_u , σ_c	Standard deviation of the slope distribution in the upwind (u) and crosswind (c) directions	$m^2 s^{-2}$	–––	**3.2.2**
	Σ	Area of the receiver telescope pupil	m^2	(4.3.13)	**4.3.2.1**
$T\ \tau$					
	τ	transmission coefficient	---		**general**
	τ_a	Optical thickness of the atmospheric path length	---	(3.4.1)	**3.4**
	τ_p	Emitted/transmitted laser pulse duration	s	(3.1.5), (4.3.10)	**3.1.2** **4.3.1**
	τ_F	Fresnel transmission at the air-water interface		(4.3.13)	**4.3.2.1**
	τ_R	Duration of the effective sounding pulse, of total response time. For Gaussian responses of all the components, we have $\tau_R{}^2 = \tau_p{}^2 + \tau_{PMT}{}^2 + \tau_{amp}{}^2 + \tau_{digit}{}^2$	s	after (4.2.8)	**4.2.2**
	$\tau_{amp}, \tau_{PMT}, \tau_{dig}$	Response time of amplifier, detector, digitizer,…	s	(4.3.10)	**4.3.1**
$\Phi\ \phi$					
	φ	latitude	rad, deg	(5.1.11)	**5.1.5**
	φ	pitch (boresight angle)	rad, deg	(5.1.4)	**5.1.2**
	Φ_{sg}	Seagrass shoot density	m^{-1}	(3.4.6)	**3.4.3**
$X\ \chi$					
	$\chi(\theta)$	Volume scattering phase function (VSPF); $\chi(\vartheta) \equiv \frac{1}{b}\beta(\vartheta)$	sr^{-1}	(3.3.9)	**3.3.2.2**
	$\chi_s(\theta)$	Small-angle (forward-scattering) component of the phase function	sr^{-1}	(4.3.32)	**4.3.2.5**

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	Α Δ Φ Θ Ρ Ω	*A B C D E F G H I J K L M N O P Q R S T U V W X Y Z*			
Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	$\tilde{\chi}_s(\mathbf{p})$	Fourier transformation of the phase scattering function $\chi_s(\mathbf{n}_t)$		(4.3.44)	**4.3.2.5**
	χ[·]	The channel Watt-count characteristic - a count-valued monotonically increasing function of argument in Watts. Describes the conversion of a continuous function to discrete (quantized) values.	counts	(4.3.2)	**4.3.1**
Ω ω					
	ω	roll (boresight angle)	rad, deg	(5.1.4)	**5.1.2**
	ω_0	Single scattering albedo, $\omega_0 = b/c$	---	(3.3.16)	**3.3.2.2**
	ω_0^*	Value of for which $Q(c^*,\omega_0)$ is minimized: $Q(c^*,\omega_0^*) = \min_{\omega_0} Q(c^*,\omega_0)$	---	(5.2.13)	**5.2**
	$\omega(t)$	Instrument response function	s^{-1}	(4.2.7)	**4.2.2**
	$\omega_{PMT}(t)$	PMT response function	s^{-1}	(4.3.9)	**4.3.1**
	$\omega_{amp}(t)$	Amplifier response function	s^{-1}	(4.3.9)	**4.3.1**
	$\omega_{dig}(t)$	Digitizer response function	s^{-1}	(4.3.9)	**4.3.1**
	Ω	The (effective) solid angle. $\Omega = \pi \Theta R^2/4$ for both Gaussian & stepmodel cases	sr	(3.3.5); Figure 3.3.6	**3.3.2.2**

	Α Δ Φ Θ Ρ Ω	*A B C D E F G H I J K L M N O P Q R S T U V W X Y Z*			
Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	Western				
A, a					
	a, $a(\lambda)$	Absorption coefficient	m^{-1}	(3.3.3)	**3.3.2.1**
	a	semi-major axis of the ellipsoid	m	(5.1.12)	**5.1.5**
		IHO order coefficient	---	(6.3.1)), Table 6.1	**6.3.3**
	$a_{bs}(k(\mathrm{z}))$	the contribution from small-angle scattering to the attenuation of spatial harmonics of the spatial frequency k in the initial distribution of radiance within a light beam when propagated over the distance z in a turbid medium	m^{-1}	(4.3.54)	**4.3.2.5**
	a_e	Effective attenuation coefficient that accounts for both absorption and scattering: $a < a_e < a + b$	m^{-1}	before Figure 4.2.6	**4.2.2**
	a_s	Effective absorption coefficient for small-angle (collimated) beam, $a_s = a + 2b_b$	m^{-1}	(4.3.34)	**4.3.2.5**
	a_{sg}	Seagrass leaf absorption coefficient	m^{-1}	(3.4.7)	**3.4.3**
	A	Area	m^2	(4.1.1)	**3.3.2.2**
	A_r	ALB receiver's aperture area	m^2	(3.1.5)	**3.1.2**
	A_{noise}	Amplitude of the signal	---	(6.2.1)	**6.2.2**
	A_{signal}	Amplitude of the noise	---	(6.2.1)	**6.2.2**
B, b					
	b	IHO order coefficient	---	(6.3.1)); Table 6.1	**6.3.3**
	b, $b(\lambda)$	(Total) scattering coefficient: $b = b_f + b_b$	m^{-1}	(3.3.7)	**3.3.2.2**
	b_b	Backward scattering coefficient	m^{-1}	(3.3.11a,b); (5.2.11)	**3.3.2.2**
	b_f	Forward scattering coefficient	m^{-1}	(3.3.11a,b); (5.2.11)	**3.3.2.2**

	$A\ \Delta\ \Phi\ \Theta\ P\ \Omega$	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z			
Letter	**Symbol**	**Quantity; description**	**SI Units**	**1st Eq. or Fig.**	**1st Sec.**
	b_{lg}	Small-angle scattering coefficient for small particles	m^{-1}	(5.2.9)	**5.2**
	b_{sm}	Small-angle scattering coefficient for small particles	m^{-1}	(5.2.9)	**5.2**
	b_s	Small-angle scattering coefficient, $b_s = b - 2b_b$	m^{-1}	(4.3.24)	**4.3.2.5**
	b_w	Small-angle scattering coefficient for hydrosol free (pure) water	m^{-1}	(5.2.9)	**5.2**
	B_{sg}	Relative biomass height distribution for a given area	m	(4.4.6)	**3.4.3**
C, c					
	c	Speed of light in the air	$m\ s^{-1}$	(3.1.5)	**3.1.2**
	$c, c(\lambda)$	Beam attenuation coefficient: $c = a + b$	m^{-1}	(3.3.13)	**3.3.2.2**
	c^*	Value of the beam attenuation coefficient that minimizes the functional Q , $Q(c^*) = \min_c Q(c)$	m^{-1}	(5.2.4)	**5.2**
	$C(Q)$	Scaling function for input energy: $C(Q) \equiv \chi[Q \cdot \max R(t)]$	---	(4.4.7)	**4.4.2**
D, d					
	d	Water depth	m	(6.3.1))	**6.3.3**
	d^{bot}	cross-section of the sounding beam near the bottom	m	(4.2.5)	**4.2.1**
	d^{sf}	diameter of the lidar beam near the water surface	m	(4.1.3)	**4.1.2**
	$\mathbf{d}_{O_w}^{SBF}$	normalized direction vector directed toward the surface point P in the SBF	---	(5.1.1)	**5.1.1**
	$\mathbf{d}_a$	a unit in-air direction vector; $\mathbf{d}_a = \boldsymbol{X}_{O_w}^{LGF}/R$	---	Figure 5.1.2, (5.1.7)	**5.1.4**
	$\mathbf{d}_w$	a unit in-water direction vector	---	Figure 5.1.2; (5.1.10)	**5.1.4**
	$\mathbf{d}_{\boldsymbol{O_w}}^{\boldsymbol{LGF}}$	In-air unit vector directed toward the surface point, P, in the local geodetic frame (LGF)	---	(5.1.6)	**5.1.3**
	$\mathbf{d}_{P_b}^{LGF}$	In-water unit vector directed toward the bottom point P_b in the local geodetic frame (LGF)	---	(5.1.9)	**5.1.4**

	Α Δ Φ Θ Ρ Ω	***A B C D E F G H I J K L M N O P Q R S T U V W X Y Z***			
Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	Δd	Depth error	m	(4.5.1)	**5.5.2**
	Δd_{sg}	Seagrass leaf thickness	m	(3.4.7)	**3.4.3**
	D(t)	Digitized output electric signal; the temporal distribution of the digitizer counts. D(t) is the final waveform and includes not only p(t) but all R(t) effects.	$counts$	(4.3.2)	**4.3.1**
	D_{const}	Digitized constant optical signal	$counts$	(4.3.4)	**4.3.1**
	$D^{exp}(t)$	experimentally-derived waveform	$counts$	(4.3.12)	**4.3.1**
	$D_Q^{calibr}(t)$	Output calibrated electrical signal	$counts$	(4.4.5)	**4.4.2**
E, e					
	e	Eccentricity of the ellipsoid	---	(5.1.12)	**5.1.5**
	E, $E(\lambda)$,$E(z,\lambda)$	Irradiance	$W{\cdot}m^{-2}$	before (3.3.1)	**3.3.1.2**
	E_0	Incident Irradiance	Wm^2	(3.3.6)	**3.3.2.2**
	E_d, $E_d(\lambda)$, $E_d(z,\lambda)$	Downwelling irradiance	Wm^2	(3.3.1)	**3.3.1.2**
	E_E, $E_E(z(t),\boldsymbol{r})$	Emitted irradiance	Wm^2	(4.3.26)	**4.3.2.4**
	E_R, $E_R(z(t),\boldsymbol{r})$,	Received irradiance	Wm^2	(4.3.26)	**4.3.2.4**
	$E_{E,R}$	Shorthand notation for *either* emitted or received irradiance	Wm^2	(4.3.31)	**4.3.2.5**
	$E_{sun}(\lambda)$	Solar irradiance at the Earth's surface	Wm^2	(3.4.4)	**3.4.2**
F, f					
	f	scan rate	s^{-1}	(4.1.4)	**4.1.2**
	f_d	detector sampling rate	s^{-1}	(4.1.9)	**4.1.2**
	$F_D(h_s)$	Function to account for the effect of forward scattering on the decay of the lidar signal with water depth	---	(5.3.3)	**5.3**

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Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
G, g					
	G	Green's function; $G(z_1, \boldsymbol{r}_1,\ \boldsymbol{n}_1;\ z_2, \boldsymbol{r}_2, \boldsymbol{n}_2)$	---	(3.3.19)	**4.3.2.3**
	G_{st}	Heaviside step function	---	(4.3.89)	**4.3.3.1.3**
	G_F	the "lidar geometric factor", $0 \le \mathrm{G_F(z)} \le 1.0$; $\mathrm{G_F(z)} = 1$ for monostatic lidars	---	(3.1.5)	**3.1.2**
H, h					
	h	ellipsoid height	m	(5.1.12)	**5.1.5**
	h_c	peak canopy height	m	(3.4.6)	**3.4.3**
	h_s	slant path in the water (in-water propagation distance along the beam center)	m	(3.4.1); Figure 4.3.6; (4.3.73)	**3.4**
	$h_s^{max}(b_s, \Theta_R)$	The maximum value of h_s for given values of b_s and Θ_R	m	after (5.3.4)	**5.3**
	h^{bot}	bottom depth	m	Figure 4.2.4	**4.2.1**
	Δh_s^{bot}	geometric stretch of the **bottom**-reflected lidar signal	m	Figure 4.2.4	**4.2.1**
	H	Thickness of an atmospheric layer	m	(3.1.1)	**3.1.1**
		height of the lidar above the sea surface	m	(4.1.1)	**4.1.1**
		heading orientation of the IBF with respect to the LGF	rad, deg	(5.1.5)	**5.1.3**
	H'	height of the lidar above the sea surface (equivalent geom.)	m	Figure 4.2.4	**4.2.1**
	H_s	slant distance between the lidar and the sea surface (along the lidar axis)	m	Before (3.1.5); Figure 4.2.1	**3.1.2; 4.2.1**
	H_s'	slant distance between the lidar and the sea surface (equivalent geometry)	m	(4.2.5); Figure 4.2.4	**4.2.1**
	ΔH_s	departure of a spherical surface from a plane surface	m	(4.2.2); Figure 4.2.2	**4.2.1**
	ΔH^{sf}	geometric stretch of the **surface**-reflected lidar signal	m	Figure 4.2.3	**4.2.1**
I, i					
	$\boldsymbol{i}$	Square root of -1	---	(3.3.2)	**3.3.2.1**

	$A\,\Delta\,\Phi\,\Theta\,P\,\Omega$	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z			
Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	$I, I(\lambda)$	Radiance **(not L)**	Wm^2sr^{-1}	(3.4.4)	**3.4.2**
	$I(t,\boldsymbol{r},\boldsymbol{n},\lambda)$	$I(t,\boldsymbol{r},\boldsymbol{n}) = I(x(t),\boldsymbol{r}_\perp,\boldsymbol{n}_\perp)$. The radiance of a monochromatic light beam at wavelength λ $\mathbf{r}$ is 3D Cartesian coordinate vector, and $\mathbf{n}$ is the 3D directional (unit) vector; $x(t)$ is the Cartesian coordinate axis along the beam axis in the water, $\mathbf{r}_\perp$ is the 2D coordinate vector in the plane perpendicular to Oz (the beam front), and $\mathbf{n}_\perp$ is the projection of $\mathbf{n}$ on the plane	Wm^2sr^{-1}		
	$I_{aE}(x,\boldsymbol{r_a},\boldsymbol{n_a})$,	Specifies $I_E(x,\boldsymbol{r},\boldsymbol{n})$ for the actual problem	Wm^2sr^{-1}	(4.3.60)	**4.3.2**
	$I'_{aE}(z,\boldsymbol{r},\boldsymbol{n})$,	The radiance of the actual emitted (E) sounding pulse in the equivalent geometry	Wm^2sr^{-1}	(4.3.60)	**4.3.2.7**
	$I'_{aR}(z,\boldsymbol{r},\boldsymbol{n})$	The radiance of the actual received (R) sounding pulse in the equivalent geometry			
	$I_{bot}(\lambda)$	Radiance reflected back from the sea floor	Wm^2sr^{-1}	(3.4.4)	**3.4.2**
	$I_E(t,\boldsymbol{r},\boldsymbol{n})$, $I_R(t,\boldsymbol{r},\boldsymbol{n})$	$I_E(t,\boldsymbol{r},\boldsymbol{n}) = I_E(x(t),\boldsymbol{r}_\perp,\boldsymbol{n}_\perp)$, $I_R(t,\boldsymbol{r},\boldsymbol{n}) = I_R(x(t),\boldsymbol{r}_\perp,\boldsymbol{n}_\perp)$ The radiance of the actual emitted (E) or received (R) pulse sounding pulse.	Wm^2sr^{-1}	(4.3.17)	**4.3.2.2**
	$I'_E(z,\boldsymbol{r},\boldsymbol{n})$, $I'_R(z,\boldsymbol{r},\boldsymbol{n})$	The radiance of the actual emitted (E) or received (R) sounding pulse in the equivalent geometry	Wm^2sr^{-1}	(4.3.16)	**4.3.2.2**
	$I'_{E,R}(z,\boldsymbol{r},\boldsymbol{n})$	Shorthand notation for *either* emitted (E) or received (R) radiance of the sounding pulse in the equivalent geometry	Wm^2sr^{-1}	(4.3.16)	**4.3**
	$I'_{E,R+}(0,\boldsymbol{r},\boldsymbol{n})$	Shorthand notation for *either* $\mathrm{I}'_E(0,\mathbf{r},\mathbf{n})$ or $I'_{R+}(z(t),\boldsymbol{r},\boldsymbol{n}')$	Wm^2sr^{-1}		**4.3**
	$I'_E(z,\boldsymbol{r},\boldsymbol{n_t})$	$I'_E(z,\boldsymbol{r},\boldsymbol{n_t}) = I'_E(z,\boldsymbol{r},\boldsymbol{n})$ when $n_z \approx 1$, $\lvert\mathbf{n}_t\rvert \ll 1$	Wm^2sr^{-1}	After (4.3.25)	**4.3.2.4**
	$I'_E(0,\boldsymbol{r},\boldsymbol{n})$ $I'_R(0,\boldsymbol{r},\boldsymbol{n})$	Normalized characteristic function of the lidar for the emitted (E) and received (R) radiance	Wm^2sr^{-1}	(4.3.16) (4.3.20)	**4.3.2.2**
	$I'_{R+}(z(t),\boldsymbol{r},\boldsymbol{n}')$	A "fictitious" radiance field describing the receiver sensitivity distribution propagating through the medium $\mathrm{I}'_{R+}(0,\mathbf{r},\mathbf{n}) \equiv \mathrm{I}'_R(0,\mathbf{r},-\mathbf{n})$, $n_z \geq 0$	Wm^2sr^{-1}	(4.3.23)	**4.3.2.4**

	Α Δ Φ Θ Ρ Ω	***A B C D E F G H I J K L M N O P Q R S T U V W X Y Z***			
Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	$I'_{R+}(z, \boldsymbol{r}, \boldsymbol{n_t})$	$I'_{R+}(z, \boldsymbol{r}, \boldsymbol{n_t}) = I'_{R+}(z, \boldsymbol{r}, \boldsymbol{n})$ when $n_z \approx 1$, $\lvert\mathbf{n}_t\rvert \ll 1$	Wm^2sr^{-1}	After (4.3.25)	**4.3.2.5**
	$I^{up}(t, z=0, \boldsymbol{r}, \boldsymbol{n})$	$I^{up}(t, z=0, \boldsymbol{r}, \boldsymbol{n})$, Upwelling (backscattered) arriving at the plane (at $z = 0$) of lidar receiver pupil	Wm^2sr^{-1}	(4.3.15)	**4.3.2.2**
	$I_\delta^{up}(t, z=0, \boldsymbol{r}, \boldsymbol{n})$	I^{up} for the case of an infinitesimal (delta function) pulse	Wm^2sr^{-1}	(4.3.19)	**4.3.2.3**
	$I_R^{norm}(0, \boldsymbol{r}, \boldsymbol{n})$	The normalized characteristic function of the lidar receiver	Wm^2sr^{-1}	(4.3.14)	**4.3.2.2**
	$\hat{I}(z, \mathbf{k}, \mathbf{n}_t)$	frequency domain expression for radiance at z		(4.3.36)	**4.3.2.5**
	$\tilde{I}(z, \mathbf{k}, \mathbf{p})$	source function: $\tilde{I}(z, \mathbf{k}, \mathbf{p}) = \frac{1}{2\pi}\int \exp(i\mathbf{n}_t\mathbf{p})\, \hat{I}(z, \mathbf{k}, \mathbf{n}_t)\, d^2\mathbf{n}_t$		(4.3.47); (4.3.79)	**4.3.2.7**
	$\hat{I}'(z, \mathbf{k}, \mathbf{n}_t)$	$\hat{I}'(\mathrm{z}, \mathbf{k}, \mathbf{n}_t) = \hat{I}(\mathrm{z}, \mathbf{k}, \mathbf{n}_t)\exp\left\{-\int_{z_0}^{z}[i\boldsymbol{n}_t\boldsymbol{k} - c]dz'\right\}$		(4.3.38)	**4.3.2.5**
	$\tilde{I}'(z, \mathbf{k}, \mathbf{p})$	$\tilde{I}'(z, \mathbf{k}, \mathbf{p}) = \dfrac{1}{2\pi}\int \exp(i\mathbf{n}_t\mathbf{p})\, \hat{I}'(\mathrm{z}, \mathbf{k}, \mathbf{n}_t) d^2\mathbf{n}_t$,		(4.3.42)	**4.3.2.5**
	$\tilde{I}'_{E,R+}(z_0, \mathbf{k}, \mathbf{k}(z))$	$\dfrac{1}{(2\pi)^2}\iint I'_{E,R+}(z_0, \mathbf{r}, \mathbf{n})\ exp\{i\mathbf{r}\mathbf{k} + i\mathbf{n}_t\mathbf{k}(z - z_0)\}\, d^2\mathbf{r}\, d^2\mathbf{n}_t$		(4.3.57)	**4.3.2.5**
J, j					
	$J_0()$	0th order Bessel function of the first kind	---	(4.3.92)	4.3.3.1.3
K, *k*					
	k	Water attenuation coefficient based on the ALB receiver's IFOV	m^{-1}	(3.4.1)	**3.4**
	$\boldsymbol{k}$	Spatial frequency resulting from the Fourier Transform of the two-2D spatial vector, $\boldsymbol{r}$	m^{-1}	(4.3.35)	**4.3.2.5**
	K_d	Diffuse attenuation coefficient (downwelling irradiance)	m^{-1}	(3.3.1)	**3.3.1.2**
	K_{sys}	System attenuation function: $K_{sys} = a + b_b$	m^{-1}	(4.3.13)	**4.3.2.1**
	$K'_{sys}(h_s)$	$K'_{sys}(h_s) = -\ln F_D(h_s)$	m^{-1}	(5.3.4)	**5.3**

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	Α Δ Φ Θ Ρ Ω	***A B C D E F G H I J K L M N O P Q R S T U V W X Y Z***			
Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
M, m					
	MPE	Maximum permissible exposure	Wm^2	(4.1.1)	**4.1.1**
	m	Complex index of refraction	---	(3.3.2)	**3.3.2.1**
		VSF shape parameter from Dolin's model $m = [0.142 - 0.132 \cdot \overline{\cos\theta}]^{-1/2}$	---	(4.3.77)	**4.3.3.1.2**
N, n					
	n	The refractive index (real part)	---	(3.3.2)	**3.3.2.1**
	$\mathbf{n}$	3D unit vector, $\mathbf{n} = \{n_z, n_x, n_y\}$; in Sec. 4.1.4, **n** is an upward normal vector at the water surface	---	Figure 3.3.4 (3.3.6)	**3.3.2.1**
	$\boldsymbol{n}'$	3D unit vector for the equivalent geometry	---	(4.3.16)	**4.3.2.2**
	n_1	Index of refraction in medium 1 (real part)	---	(3.2.1)	**3.2.1**
	n_2	Index of refraction in medium 2 (real part)	---	(3.2.1)	**3.2.1**
	$\mathbf{n_0}$	unit vector specifying the incident direction	---	Figure 3.3.4	**3.2.1**
	$\mathbf{n_1}$	Unit vector in the direction of beam propagation	---	(4.3.18)	**4.3.2.2**
	$\mathbf{n_2}$	Unit vector in the direction of scattered radiation	---	(4.3.18)	**4.3.2.2**
	$\mathrm{n_a}$	Index of refraction of air	---	Figure 3.2.1	**3.2.1**
	$\mathbf{n_a}$	specifies the unit vector $\boldsymbol{n}$ in the actual problem	---	before (4.3.60)	**4.3.2.7**
	$\mathbf{n_{a\,t}}$	Specifies $\boldsymbol{n}_t$ for the actual problem; $\mathbf{n}_{at} \equiv (n_{a=}, n_{a\perp})$	---	(4.3.60); Figure 4.3.5	**4.3.2.7**
	$n_{a=}$ and $n_{a\perp}$	Transverse components of the 3D directional vector $\mathbf{n}_a$	---	(4.3.64)	**4.3.2.7**
	n_i	The refractive index (imaginary part); $n_i = a\lambda/4\pi$	---	(3.3.2)	**4.3.2.1**
	$\mathbf{n_t}$	$\boldsymbol{n_t} = \{n_x, n_y\}$; then $\mathbf{n} = \{n_z, n_x, n_y\} = \{n_z, \mathbf{n}_t\}$	---	(4.3.30); Figure 4.3.5	**4.3.2.4**
	n_w	Index of refraction of water	---	Figure 3.2.1	**3.2.1**

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Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	n_z	Component of the unit vector, **n,** oriented along the receiver axis.	---	Figure 4.3.3	**4.3.2.2**
O, o					
	O_IBF	The origin of the IMU body frame (IBF) coordinate system, located at the IMU center	---	(5.1.3)	**5.1.2**
	O_LGF	The origin of the LGF coordinate system	---	Figure 5.1.2	**5.1.3**
	O_SBF	The origin of the sensor-body-frame (SBF) coordinate system	---	Before (5.1.2)	**5.1.2**
	O	Location of the beam axis at the lidar	---	Figure 4.2.4	**4.2.1**
	O_b	Location of the beam axis at the bottom	---	Figure 4.2.4	**4.2.1**
	O_w	Location of the beam axis at the water surface	---	Figure 4.2.4	**4.2.1**
	O'	Location of the lidar receiver in the equivalent geometry	---	Figure 4.2.4	**4.2.1**
P, p					
	$p(t)$	Transmitted pulse shape (time-dependent); Normalized s.t. $\int_0^\infty p(t)\,dt = 1$	s^{-1}	(4.3.6)	**4.2.2**
	$\mathbf{p}$	the frequency domain version of $\mathbf{n}_t$		(4.3.42)	**4.3.2.5**
	P	pitch orientation of the IBF with respect to the LGF	rad, deg	(5.1.5)	**5.1.3**
	$P(r)$	Total measured power at r	W	(3.3.14)	**3.3.2.2**
	P_a	Power absorbed	W	(3.3.4)	**3.3.2.2**
	P_{atm}	Power backscattered by the atmosphere	W	(3.1.5)	**3.1.2**
	P_{bot}	Laser power returning from seafloor	W	(3.4.1)	**3.4**
	$\vec{P}_G$	Vector offset between the laser unit and the IMU body frame with respect to the laser unit coordinate system	m	(6.3.1)	**6.3.2**
	P_i	Incident radiant power	W	(3.3.4); Figure 3.3.8	**3.3.2.2**
	P_{noise}	Background noise in the lidar return	W	(6.2.1)	**6.2.2**

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Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	P_0	Laser output power; The actual transmitted laser pulse power is $W \cdot p(t)$ with W being the pulse energy (Sec. 2.3.2.2)	W	(3.1.5)	**3.1.2**
	$P_s, P_s(\boldsymbol{n})$	Power scattered (in direction **n)**	W	(3.3.5)	**3.3.2.2**
	P_{signal}	Signal in the lidar return	W	(6.2.1)	**6.2.2**
	PRF	Pulse repetition frequency	s^{-1}	(4.1.1)	**4.1.1**
Q, q					
	Q	Transmitted pulse energy	J	(4.1.1)	**4.1.1**
	Q'	Transmitted pulse energy in the equivalent geometry, $Q^{eq} = Q \cdot \tau_F^2$	J	(4.3.16)	**4.3.2.2**
R, r					
	r	distance	m	(3.3.4); Figure 3.3.6	**3.3.2.2**
		range (distance from the lidar)	m	(4.1.8)	**4.1.3**
	r_a	range (distance from the lidar)	m	(5.1.2)	**5.1.2**
	r_N	the position in the ECEF coordinates, $r_N = \frac{a}{\sqrt{1-e^2\sin^2\varphi}}$	m	(5.1.12)	**5.1.5**
	Δr	range resolution	m	(4.1.9)	**4.1.3**
	r_E	Initial sounding beam radius	m	(4.3.60)	**4.3.2.7**
	$r_=$	the separation distance from the principal line of a point on the leading-edge plane	m	(4.3.58); Figure 4.3.4	**4.3.2.6**
	$r_\perp$	The component of **r** perpendicular to the plane of incidence	m	(4.3.64); Figure 4.3.5	**4.3.2.7**
	$\mathbf{r}$	A 2D vector, $\mathbf{r} = (r_x, r_y)$, describing the location on the $\mathbf{n}_t$ plane	m	Figure 4.3.3; (3.3.14)	**4.3.2.2**
	$\mathbf{r}_a$	the 2D coordinate vector perpendicular to the beam axis	m	(4.3.60)	**4.3.2.4**
	R	Reflectance coefficient (unpolarized light)	---	(3.2.2)	**3.2.1**
		roll orientation of the IBF with respect to the LGF	rad, deg	(5.1.5)	**5.1.3**

	Α Δ Φ Θ Ρ Ω	*A B C D E F G H I J K L M N O P Q R S T U V W X Y Z*			
Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	$R(t)$	The channel response to lidar pulse (including laser pulse and electronic response), or **effective sounding pulse shape.** $R(t) \equiv p(t) * \omega(t)$.	s^{-1}	(4.2.7); (4.2.8)	**4.2.2; 4.3.1**
	$R_{\parallel}$	Reflection coefficient parallel polarized radiation	---	(3.2.2)	**3.2.1**
	$R_{\perp}$	Reflection coefficient perpendicular polarized radiation	---	(3.2.2)	**3.2.1**
	R_{∞}	Remote sensing reflectance over optically deep waters	---	(3.4.5)	**3.4.3**
	R_b	Remote sensing bottom reflectance	sr^{-1}	(3.4.5)	**3.4.3**
	R_{RS}	Remote sensing reflectance	sr^{-1}	(3.4.5)	**3.4.3**
	$R_{yaw,pitch,roll}$	the rotation matrix between the Inertial Navigation System (INS) body and the mapping frame	---	(6.3.1)	**6.3.1**
	$R_{\alpha,\beta}$	the scan angle rotation in the laser sensor frame	---	(6.3.1)	**6.3.1**
	$R_{\Delta\omega,\Delta\varphi,\Delta x}$	the boresight rotation matrix between the laser frame and the INS body frame	---	(6.3.1)	**6.3.1**
	R_{∞}	Remote sensing reflectance over optically deep waters	sr^{-1}	(3.4.5)	**3.4.3**
	$\boldsymbol{R}_{LGF}^{ECEF}$	rotation matrix that transforms an arbitrary position vector in LGF to the position vector in ECEF	-	(5.1.11)	**5.1.5**
	$\boldsymbol{R}_{O\_LGF}^{ECEF}$	rotation matrix to transform the geodetic position of O_LGF into the position in ECEF coordinates	-	(5.1.12)	**5.1.5**
	$\boldsymbol{R}_{SBF}^{IBF}$	rotation matrix to transform $\boldsymbol{X}_P^{SBF}$ to $\boldsymbol{X}_P^{IBF}$	-	(5.1.3)(5.1.4)	**5.1.2**
	$\boldsymbol{R}_{IBF}^{LGF}$	rotation matrix to transform $\boldsymbol{X}_P^{IBF}$ to $\boldsymbol{X}_P^{LGF}$	-	(5.1.5)	**5.1.3**
	$R_{yaw,pitch,roll}$	boresight matrix between the laser frame and the INS body frame	---	(6.3.1)	**6.3.2**
	$R_{\alpha,\beta}$	scan angle rotation in the laser sensor frame	---	(6.3.1)	**6.3.2**
	$R_{\Delta\omega,\Delta\phi,\Delta\kappa}$	boresight matrix between the laser frame and the INS body frame	---	(6.3.1)	**6.3.2**

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Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	$R_{\Omega,\Phi,\mathrm{K}}$	Rotation matrix for the co-alignment between test strips	---	(6.3.2)	**6.3.2**
S, s					
	s	the 2D Cartesian coordinate vector in the plane parallel to the water surface	m	Before (4.3.64); Figure 4.3.5	**4.3.2.4**
	$s_{=}$	The component of **s** parallel to the plane of incidence	m	(4.3.64)	**4.3.2.4**
	$s_{\perp}$	The component of **s** perpendicular to the plane of incidence	m	(4.3.64)	**4.3.2.4**
	S	Scale factor for geo-location	---	(6.3.2)	**6.3.2**
	$S^{back}(t)$	Power of the elastic backscattering signal from the water column.	W	(4.3.12)	**4.3.2.1**
	$S_{\delta}(t)$	The "impulse response function" (ImpRF). The input optical signal - temporal distribution of signal light power at the detector input FOR DELTA_SHAPED transmitted pulse	W	(4.2.6)	**4.2.2**
	$S_{\delta}^{back}(t)$	Power of the elastic backscattering signal from the water column for the infinitesimal pulse.	W	(4.3.20)	**4.3.2.3**
	$S_{p}(t)$	The "environmental response function" (EnvRF). The actual input optical signal - temporal distribution of signal light power at the detector input FOR ACTUAL transmitted pulse of the shape $p(t)$	W	(4.2.6)	**4.2.2**
	S_{const}	A constant optical signal	W	(4.3.4)	**4.3.1**
	$S_{R}(t)$	The “real waveform” retrievable from the output lidar signal	W	(4.2.8)	**4.2.2**
	$S_{R}^{exp}(t)$	Experimental optical signal, the “real” waveform	W	(4.3.12)	**4.3.1**
	$S_{R}^{sim}(t)$	Simulated signal	W	(5.2.2)	**5.2**
	$S_{Q}^{calib}(t)$	Calibration input optical signal	W	(4.4.4)	**4.4.2**
	SW	Swath width	m	(4.1.2)	**4.1.2**

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Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
T, t					
	t	time	*s*	(4.1.8)	**general**
	Δt	Time interval between consecutive observations	*s*	(4.1.9)	**4.1.3**
		Time difference (Δt) between two peak positions or half-peak positions	*s*	(4.5.1)	**5.5.2**
	t_-	Time corresponding to a near-surface horizon deep enough to obviate the need to account for surface effects.	*s*	(5.2.3)	**5.2**
	t_+	Time corresponding to a near-bottom horizon for which bottom reflection is still undetected.	*s*	(5.2.3)	**5.2**
	t_a	time of travel from O_LGF to the first peak of the waveform	*s*	Figure 5.1.2	**5.1.4**
	t_i	time of travel of experimental waveforms within the interval, $t_- \leq t_i \leq t_+$	*s*	Below (5.2.3)	**5.2**
	Δt_{HP}^{bot}	Bias of the estimated location of the bottom relative to the true location using the half peak (HP) algorithm	*m*	Figure 5.5.4	**5.5.2**
	Δt_{P}^{bot}	Bias of the estimated location of the bottom relative to the true location using the peak (P) algorithm	*m*	Figure 5.5.4	**5.5.2**
	Δt_{HP}^{surf}	Bias of the estimated location of the water surface relative to the true location using the half peak (HP) algorithm	*m*	Figure 5.5.4	**5.5.2**
	Δt_{P}^{surf}	Bias of the estimated location of the surface relative to the true location using the peak (P) algorithm	*m*	Figure 5.5.4	**5.5.2**
	t_w	time of travel from the first peak of the waveform to the bottom point, O_b	*s*	Figure 5.1.2	**5.1.4**
	t^{bot}	time the central part of the pulse arrives at the bottom	*s*	Figure 4.2.4	**4.2.1**
	Δt^{bot}	bottom-reflected pulse duration	*s*	Figure 4.2.4	**4.2.1**
	t^{sc}	$t^{sc}(b_s, \Theta_R) \equiv 2h_s^{max}(b_s, \Theta_R)/nc$, the upper limit of the backscattered signal argument that corresponds to a negligible impact of forward scattering	*s*	(5.3.5)	**5.3**
	t^{sf}	time that light from the central part of the pulse front, after reflection from the water surface, arrives at the receiver	*s*	Before (4.2.4); Figure 4.2.3	**4.2.1**
	Δt^{sf}	surface-reflected pulse duration (geometrical stretch of the surface-reflected pulse)	*s*	(4.2.4); Figure 4.2.3	**4.2.1**

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Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	$T(H,\lambda)$	Two-way atmospheric transmission term	---	(3.1.1)	**3.1.1**
U, u					
V, v					
	v	velocity	kts, ms^{-1}	(4.1.8)	**4.1.4**
	V_r	Visual range: the distance at which an object can be seen with the unaided eye. The visual range is determined only by the contrast of an object with its background,	m	(3.1.3)	**3.1.1**
	V	volume	m^3	(3.3.6); Figure 3.3.7	**2.3.2.2**
	V_{lg}	volume concentrations for large suspended particles	m^{-1}	(5.2.7)	**5.2**
	V_{sm}	volume concentrations for small suspended particles	m^{-1}	(5.2.8)	**5.2**
	v_{plat}	airborne platform velocity	kts	(4.1.4)	**4.1.2**
W, w					
	W	cluster constant: $W = \exp(-2\tau_a)/(H_s n_w + h_s)^2$	m^{-2}	(3.4.2)	**3.4**
X, x					
	Δx	along track sample spacing	m	(4.1.4)	**4.1.2**
	$(x_{q_i}, y_{q_i}, z_{q_i})$	Vector position of a point cloud	m	(6.3.2)	**6.3.2**
	$(X_T, Y_T, Z_T)^T$	translation vector between test strips	m	(6.3.2)	**6.3.2**
	$\boldsymbol{X}_{O_w}^{ECEF}$	Position vector in ECEF coordinates	m	(5.1.13)	**5.1.5**
	$\boldsymbol{X}_{O\_LGF}^{ECEF}$		m	(5.1.13)	**5.1.5**
	$\boldsymbol{X}_{O_{SBF}}^{IBF}$	lever-arm vector to the SBF origin in the IMU Body Frame (IBF)	m	(5.1.13)	**5.1.2**

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Letter	***Symbol***	***Quantity; description***	***SI Units***	***1st Eq. or Fig.***	***1st Sec.***
	$\boldsymbol{X}_{O_w}^{IBF}$	position vector to a surface lidar return point, O_w, in a local geodetic frame (LGF)	m	(5.1.6)	**5.1.3**
	$\boldsymbol{X}_{O_w}^{LGF}$	position vector to a surface lidar return point, O_w, in a local geodetic frame (LGF)	m	(5.1.6)	**5.1.3**
	$\boldsymbol{X}_{P_b}^{LGF}$	position vector to a bottom lidar return point, O_b, in a local geodetic frame (LGF)	m	(5.1.10)	**5.1.4**
	$\boldsymbol{X}_{O_w}^{SBF}$	Position vector of the lidar point, O_w, in the Sensor Body Frame (SBF)	m	(5.1.3)	**5.1.2**
	$\vec{X}_G$	Vector ground position	m	(6.3.1)	**6.3.2**
	$\vec{X}_0$	Vector from the origin of the ground coordinate	m	(6.3.1)	**6.3.2**
Y, y					
	Δy	cross-track sample spacing	m	(4.1.5)	**4.1.2**
Z, z					
	z	Distance from the lidar	m	(3.1.1)	**3.1.1**
	z	water depth variable	m	(3.3.1)	**3.3.2**
	z	distance along the slant path	m	Figure 4.3.3	**4.3.2.2**
	z_0	the lidar altitude above the interface in the equivalent problem, $z_0 = H'$	m	Before (4.3.4);	**4.3.2.5**
	$z(t)$	Total distance of the source from the leading edge, $z(t) \equiv ct/2n$	m	(4.3.58)	**4.3.2.6**
	z_a	Distance along the beam axis from the pupil plane	m	Figure 4.3.4; (4.3.60)	**4.3.2.6**
	z_t	the in-water path of a ray traveling along the lidar axis	m	(4.3.57)	**4.3**
	$z_w(t, r_=)$	distance covered by a ray traveling from the water surface to the leading-edge plane along a path that is parallel to the lidar axis	m	(4.3.58)	**4.3.2.6**
	$z_{sf}(\boldsymbol{r})$	notates when the variable $\{z(r)\}$ lies exactly on the water surface.	m	(3.1.1)	**4.3.2.4**